Monte Carlo Methods for Thermal Radiative Transfer

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Todd Urbatsch

and

Tom Evans, Jim Morel, Henry Lichtenstein

Los Alamos National Laboratory

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- The *Milagro* Implicit Monte Carlo Code
  - multi-dimensional, multi-geometry
  - parallel, reproducible
  - software design
  - verification
- Hybrid Monte Carlo
  - equilibrium thermal radiative diffusion
- Residual Monte Carlo

Monte Carlo Methods for Thermal Radiative Transfer

Abstract

We present an overview of the Monte Carlo methods for thermal radiative transfer to be discussed during a visit to VNIIEF, Serov, Russia, January 27-31, 2003.

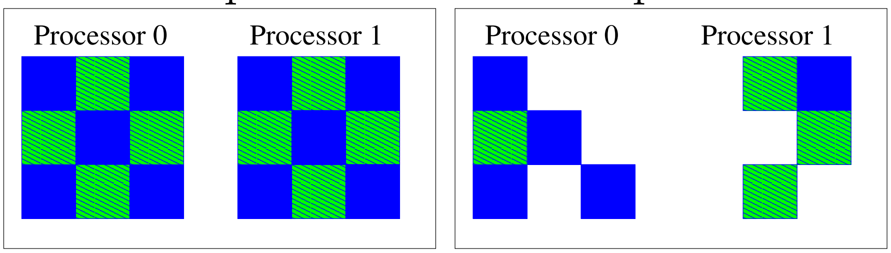
Implicit Monte Carlo Code
We have a code called Milagro that is parallel and reproducible, and it considers either domain replication or domain decomposition for its parallelism. Milagro is a multi-dimensional and multi-geometry C++, object-oriented code. Its physics components are general in that each component can works with a choice of many mesh types. Our mesh types include an orthogonal-structured Cartesian mesh, an "RZWedge", and a tet mesh, the latter of which isn't quite integrated yet. We practice Software Quality Engineering practices such as unit testing, Design-by-Contract, regression testing, etc. Beyone software verification, we verify the mathematics by comparing to analytic solutions such as Marshak Waves and the Su-Olson set of analytic benchmarks.

Hybrid Monte Carlo
I presented a neutronics hybrid Monte Carlo method at the ANS Math. & Comp. Topical meeting in Madrid in 1999. We have since extended this hybrid Monte Carlo method to equilibrium diffusion (radiative transfer). We call the method EqDDMC for Equilibrium Discrete Diffusion Monte Carlo.

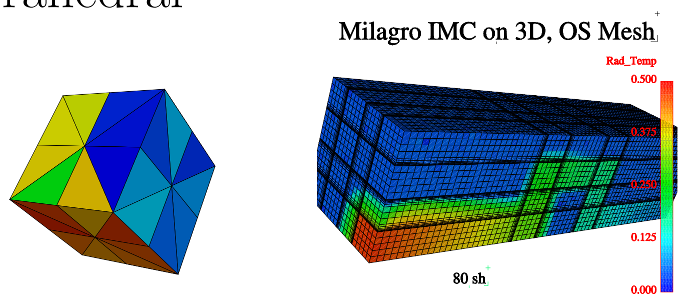
Residual Monte Carlo
We have applied Halton's "Sequential Monte Carlo" method to the EqDDMC method. In the residual method, the equation for solving the additive correction, or residual, takes exactly the same form as the equation for solving the full solution. Thus, within a timestep, we perform batches with small numbers of particles, whereby each batch produces a correction to that timestep's solution. Within a timestep, we see several orders of magnitude improvement. In a nonlinear calculation, such as a Marshak Wave, we see a few orders of magnitude improvement.

The *Milagro* IMC Code

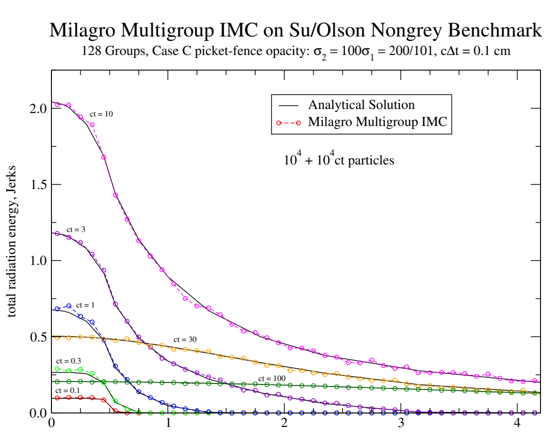
- parallel
  - domain replication or decomposition

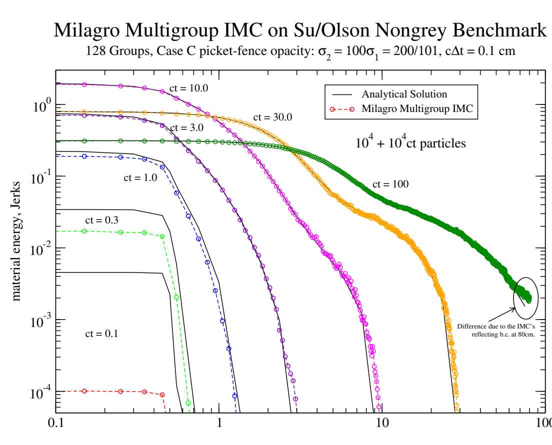


  - reproducible
- C++, object-oriented, templated on Mesh Type
  - orthogonal structured AMR, RZWedge AMR
  - tetrahedral



- verification of software and physics





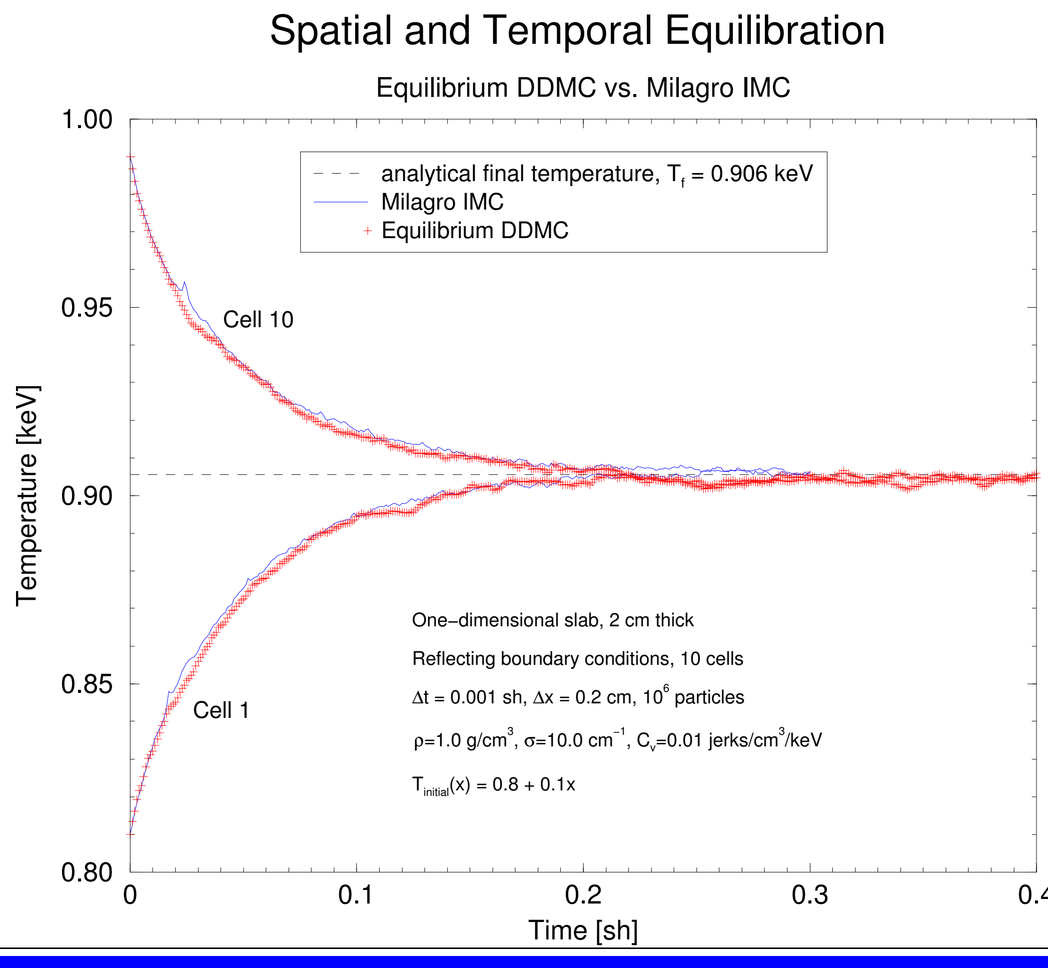
Hybrid Monte Carlo/Deterministic

Equilibrium Discrete Diffusion Monte Carlo (EqDDMC) Method

- equilibrium diffusion for thermal radiative transfer

$$(C_v + 4aT^3)\frac{\partial T}{\partial t} - \frac{\partial}{\partial x}\frac{4acT^3}{3\sigma_{\mathrm{R}}}\frac{\partial T}{\partial x} = 0$$

- Monte Carlo particles traverse discrete space
- extension of neutronics methods presented at the ANS Math. & Comp. Topical Meeting in Madrid, Spain, 1999



Residual Monte Carlo

- Apply Halton's Sequential MC method to EqDDMC

$$\hat{A}x = b$$

If $\tilde{x}$ is an approximate solution, its error is

$$\delta\tilde{x} = x - \tilde{x}$$

$$\hat{A}\delta\tilde{x} = \texttt{residual} = b - \hat{A}\tilde{x}$$

- Solve for $\delta\tilde{x}$ instead of the solution
- Use the same EqDDMC method, except in batches
- Possible to begin each timestep with a guess
- Possible to iterate nonlinearities to convergence
- Several orders of magnitude improvement per timestep; a few orders of magnitude improvement overall